Developing Smart Seismic Arrays

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Seismic imaging and tracking methods have intelligence and monitoring applications. Current systems, however, do not adequately calibrate or model the unknown geological heterogeneity, nor are they designed for rapid data acquisition and analysis in the field. This project seeks to build the core technological capabilities, coupled with innovative deployment, processing, and analysis methodologies, to allow seismic methods to be used effectively in seismic imaging and vehicle tracking where rapid (minutes to hours) and real-time analysis is required.

The goal of this project is to build capabilities in acquisition system design and application, and in full 3-D finite-difference modeling, as well as statistical characterization of geological heterogeneity. Such capabilities, coupled with a rapid field analysis methodology, based on matched-field processing, are applied to problems associated with surveillance, battlefield management, detection of hard and deeply buried targets, and portal monitoring. This project benefits the U.S. military and intelligence communities in support of LLNL's national security mission.

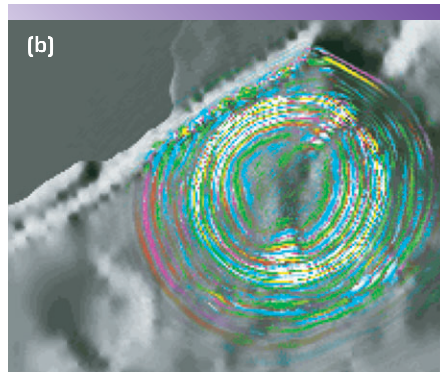
FY03 was the final year of this project. In the two and a half years this project has been active, numerous and varied developments and milestones have been accomplished. A wireless communication module was developed to facilitate rapid seismic data acquisition and analysis. The E3D code was enhanced to include topographic effects. Codes were developed to implement the Karhunen-Loeve (K-L) statistical methodology for generating geological heterogeneity that can be used in E3D modeling. The matched-field processing methodology applied to vehicle tracking, and based on a field calibration, to characterize geological heterogeneity was tested and successfully demonstrated in a tank tracking experiment at the Nevada Test Site (NTS). A 3-seismic- array vehicle tracking testbed was installed on site at LLNL for real-time seismic tracking methods. A field experiment was conducted over a tunnel at NTS that quantified the tunnel reflection signal and, coupled with modeling, identified key requirements in experimental layout of sensors.

A large field experiment was conducted at the Lake Lynn Laboratory (Fig. (a)), a mine safety research facility in Pennsylvania, over a tunnel complex in realistic, difficult conditions. This experiment gathered the necessary data for a full 3-D attempt to apply the methodology, and to analyze the capabilities to detect and locate in-tunnel explosions.

In FY03 specifically, a large and complex simulation experiment was conducted that tested the full modeling-based approach to geological characterization using E3D, the K-L statistical methodology, and matched-field processing applied to tunnel detection with surface seismic sensors. The simulation validated the full methodology and the need for geological heterogeneity to be accounted for in the overall approach. The Lake Lynn site area was geologically modeled using the code Earthvision to produce a 32-million node 3-D model grid for E3D (Fig. (b)).

Model linking issues were resolved and a number of full 3-D model runs were accomplished using shot locations that matched the data. E3D-generated wavefield movies showed that the reflection signal would be too small to be observed in the data due to trapped and attenuated energy in the weathered layer. An analysis of the few sensors coupled to bedrock did not improve the reflection signal strength sufficiently because the shots, though buried, were within the surface layer, and hence attenuated. Ability to model a complex 3-D geological structure and calculate synthetic seismograms that are in good agreement with actual data (especially for surface waves and below the complex weathered layer) was demonstrated. We conclude that E3D is a powerful tool for assessing the conditions under which a tunnel could be detected in a specific geological setting.

Finally, the Lake Lynn tunnel explosion data was analyzed using standard array-processing techniques, with the result that single detonations could be detected and located but simultaneous detonations would require a strategic placement of arrays.



(a) Surface seismic shot detonation at the Lake Lynn site during field experiment. (b) Map view of the surface wavefield potential calculated by E3D for (a). P-waves are magenta; S-waves are turquoise. Simulations verify that advanced signal processing methods are required to detect and image underground facilities.